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OPTIMUM PROBING FOR AVALANCHE VICTIMS

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Introduction

The technological problems connected with the development of a "wonder searching instrument" are immense. Until science presents us with this instrument we must use classical search devices. At present, the avalanche dog and the avalanche probe are in most general acceptance. Should the avalanche dog fail, or not be available as is the case in so many localities, the victim's chances depend on the effectiveness of a probing operation.

This paper will examine probing methodology and attempt to justify a set of guidelines for the rescue leader to follow.

Each avalanche disaster is unique and ultimately the rescue leader makes certain decisions to maximize the victim's chances of survival within the limitations of a safe and sane operation. Very often the rescue leader must choose between various courses of action; the correct choice is the one which gives the highest probability of finding the victim alive. This choice may not be the same one which will give the highest probability of simply finding the victim - dead or alive.

Specifically, three judgement decisions will be discussed. Resolving these three decisions is of intrinsic importance. However, equally important are the possibilities of extending the proposed solutions to related rescue problems. The three specific judgement decisions in question are:

What is the optimum depth for coarse probing?

How many times should the coarse probe be repeated before utilizing the fine probe?

How much time should be budgeted to the search of a subregion within the main avalanche area?

Summary

I. **What is the optimum depth for coarse probing?**

A review of the calculations and table 1 in this report indicates that an initial coarse probe depth of at least 3 meters is desirable.

II. **How many times should the coarse probe be repeated before using the fine probe?**

A review of table 2 indicates that initial use of the coarse probe is clearly justified. For the smaller avalanche, it also shows significant gains in the victim's chances with repetitive use of the coarse probe. For larger avalanches, the gains in repeating the coarse probe are not as significant; the rescue leader may feel justified in going to the fine probe after one coarse probe.

III. **How much time should be budgeted to the search of a subregion within the main avalanche area?**

The answer to this question depends on many factors such as deposition configuration, size of avalanche, manpower available and natural obstacles, which will influence the judgement of the rescue leader. However, a review of figure 3 indicates that rescue groups can increase the victim's chances by first efficiently searching probable subregions.

Every avalanche rescue is a different problem in itself. However, probability calculations based upon a general, or average, avalanche occurrance gives well supported answers to the questions.

Supporting Data and Calculations

Applying these three questions to a general avalanche disaster and thereupon attempting a general solution would be a tedious mathematical exercise. Certain factors such as the size of the avalanche, the density of the snow, and the time interval between the avalanche and the initiation of probing would be carried as variables. The problem is greatly simplified if these factors are preset. Large avalanches, high density snow, and long rescue

approach marches all reduce the victim's probability of being found alive. In this paper the rescuers and the victim will be given a fighting chance by the introduction of the following situation which is typical of avalanche disasters occurring in the vicinity of lift serviced ski areas:

a. The avalanche size facilitates a coarse probe time of an hour or less.

b. Probing begins within 0.5 hours after the avalanche occurrence.

As a further simplification, density of snow is removed as a variable by considering non-density dependent statistics.

The solutions will be largely based on the following probability theorem as applied to avalanche work by deQuervain[1]:

$$P_{FA} = P_F P_A \qquad \text{equation 1.}$$

where P_{FA} = probability of finding the victim alive.

P_F = probability of finding the victim.

P_A = probability of the victim being alive.

For avalanches under consideration in this paper a fine probing search gives essentially:

$$P_F = 1$$

According to data worked out by Schild[2] for a coarse probing search:

$$P_F = 0.76$$

P_A (t) can be derived from the collected history of the accruing number of avalanche accidents. Figure 1. displays P_A (t) for the two depth ranges $z < 1$ and $1 \leq z \leq 3$. Where z is the depth measure in meters from the top of the snow. The curves shown in Figure 1. are based on Swiss data[1]. Changes in the shapes of these curves may be brought about by the future compilation

of avalanche statistics. In their present form, however, they represent a sufficiently good approximation for use in the following solutions:

I. <u>What is the optimum depth for coarse probing?</u>

Probing rate experiments were conducted at Alta, Utah, in the spring of 1967. The probed snow was damp and compact. It offered medium resistance to probe penetration. A 100 yard course was set up and five probing passes each were made for the depths: one, two, and three meters. The rates were found to be in respective ratio:

$$1:1.8 \quad : \quad 2.5$$

Consider these two avalanches for comparison:

Case a......................an avalanche requiring a one meter deep coarse probe operation of 0.25 hours.

Case b......................an avalanche requiring a one meter deep coarse probe operation of 0.50 hours.

Utilizing the experimental rate ratio: 1:1.8:2.5 the following table of probing times can be constructed:

	one meter	two meters	three meters
Case a	0.25 hours	0.45	0.63
Case b	0.50	0.90	1.35

Figure 2. shows three linear approximations to the P_A (t) of Figure 1.

$Z = 1 \qquad P_A(t) = 0.78 - 0.20t$

$Z = 2 \qquad P_A(t) = 0.73 - 0.25t$

$Z = 3 \qquad P_A(t) = 0.61 - 0.26t$

For a probing operation:

$$P_A = \frac{1}{\Delta t} \int_{\Delta t} P_A(t)\,dt \qquad \text{Equation 2.}$$

where Δt is the time to perform the operation. This definition of P_A which uses the average value of P_A (t) instead of a more rigorous integral

minimizes the computations and is a reasonable approximation within the framework of the desired results. Equation 2. can be evaluated at all three depths for cases a and b by using the functions shown in Figure 2 and the constructed table of probing times. The results are summarized in the P_A column of Table 1.

To complete the solution, P_F values must be developed. The burial depth of a victim in a slide is dependent on many complicated factors such as the geometry of the slide area and deposition zone, the position of the victim when first caught, the victim's own efforts to keep above the snow, the turbulent eddies of snow and air, etc. The rescue leader may be able to assess some of these factors but the overall situation is usually not clear and the victim can be given equal probabilities for being found at all points in the z direction. Thus, for a three meter deep deposition:

one meter deep coarse probing.... $P_F = (0.76)\ (0.33) = .25$

two meter deep coarse probing.... $P_F = (0.76)\ (0.67) = .51$

three meter deep coarse probing.. $P_F = (0.76)\ (1.00) = .76$

These P_F values are summarized in the P_F values shown in Table 1. Within the limits of this study the P_{FA} values indicate that a <u>reduction in coarse probe depth is not justified in the interest of speed.</u>

TABLE 1

Probing Depth (meters)	Probing Time (hours)	P_F (%)	P_A (%)	P_{FA} (%)
1	0.25	25	66	17
1	0.50	25	63	16
2	0.45	51	54	28
2	0.90	51	48	24
3	0.63	76	40	30
3	1.25	76	32	24

II. <u>How many times should the coarse probe be repeated?</u>

To begin, this question is analogous to the coin tossing problem: A coin has been tossed and it turned up "heads". What is the probability it will turn up "heads" on the next toss? The answer is 50%. Applying this reasoning to the probing operation it appears that if the initial use of the coarse probe gives the highest probability of finding the victim alive then the coarse probe should be repeated over and over again until the victim is found.

Very often rescue leaders arbitrarily decide not to repeat the coarse probe. Sometimes in consideration of the hopelessness of the victim's chances and the condition of the rescuers this may be the proper and only reasonable decision. However, the rescue leader's decision should be guided by weighing the applicable probabilities.

According to Schild[2], the fine probe takes four times as long to complete as the coarse probe. Again two different sized avalanches will be discussed:

Case a............an avalanche requiring a coarse probe time of 0.25 hours and hence a fine probe time of 1 hour.

Case b............an avalanche requiring a coarse probe time of 1 hour and hence a fine probe time of four hours.

Also, as before, the search will be assumed to begin at t=0.5 hours.

In Figure 1, the $P_A(t)$ for a two meter deep burial will be used. Since this second study covers a time interval several hours long the linear approximation for $P_A(t)$ is replaced by:

$$P_A(t) = 0.66e^{-0.88t} \qquad \text{Equation 3}$$

which was derived by applying the method of least squares to the data of Figure 1.

The victim's total chances for being found alive by an operation involving two sequential probes can be expressed as:

$$P_{FA} = P_1 + P_2 - P_1P_2 \qquad \text{Equation 4}$$

where P_1 is the probability of finding the victim alive by the first probe and P_2 is the probability of finding the victim alive by the second probe. By making use of equations one through four, Table 2 can be constructed.

TABLE 2

Coarse Probe Time (Hours)	No. of Coarse Probes Before Making Fine Probe	P_{FA} (%)
0.25	0	18
0.25	1	31
0.25	2	39
0.25	3	45
0.25	4	49
1.00	0	8
1.00	1	18
1.00	2	20
1.00	3	21
1.00	4	21

The initial use of the coarse probe is clearly justified. For the smaller avalanches, Table 2 shows <u>significant gains in the victims chances with repetitive use of the coarse probe.</u> For larger avalanches the gains in repeating the coarse probe are not as significant and the rescue leader may feel justified in going to the fine probe after one coarse probe.

III. How much time should be budgeted to the search of a subregion the main avalanche area?

Figure three shows various deposition configurations. The rescue leader is sometimes faced with the dilemma of having to search for a victim buried in one of two possible regions. The rescue group may have insufficient man power or probes to simultaneously search both regions. How does the group budget its operation?

Once again certain simplifying assumptions will be made, the search will begin at t=0.5 hours. The total avalanche area can be searched in two hours. Under these conditions the victim has a 20% chance of being found alive. A competent rescue leader can increase the victim's chances if he is able to designate likely subregions for first priority search and if these subregions can be searched effectively and quickly. The results of applying equations one through four to this problem are summarized in Table 3.

TABLE 3

	P_F in Subregion (%)				
	10	20	30	40	50
Time spent in initial search of subregion (hours)	P_{FA} (%)				
0.25	18	21	24	27	31
0.50	16	19	22	25	28
0.75	13	16	19	21	24
1.00	11	14	16	19	19

CONCLUSIONS

The results of these probability calculations re-enforce contemporary probing procedures. An initial coarse probe of at least three meters deep has been given mathematical support. The repetition of the coarse probe before resorting to a fine probe is beneficial, especially for the smaller avalanches. Rescue groups can increase the victim's chances by first efficiently searching probable subregions.

BIBLIOGRAPHY

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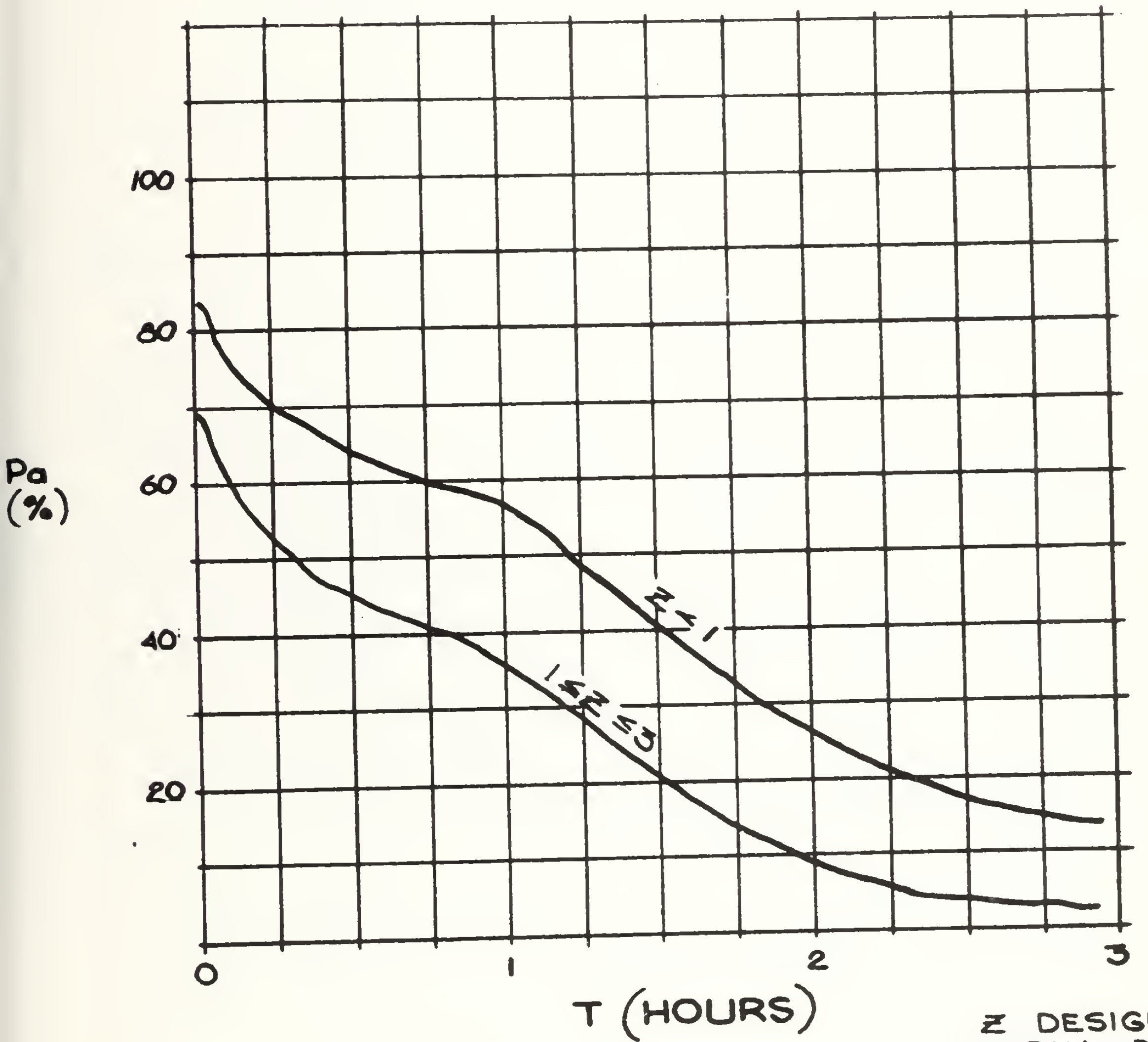
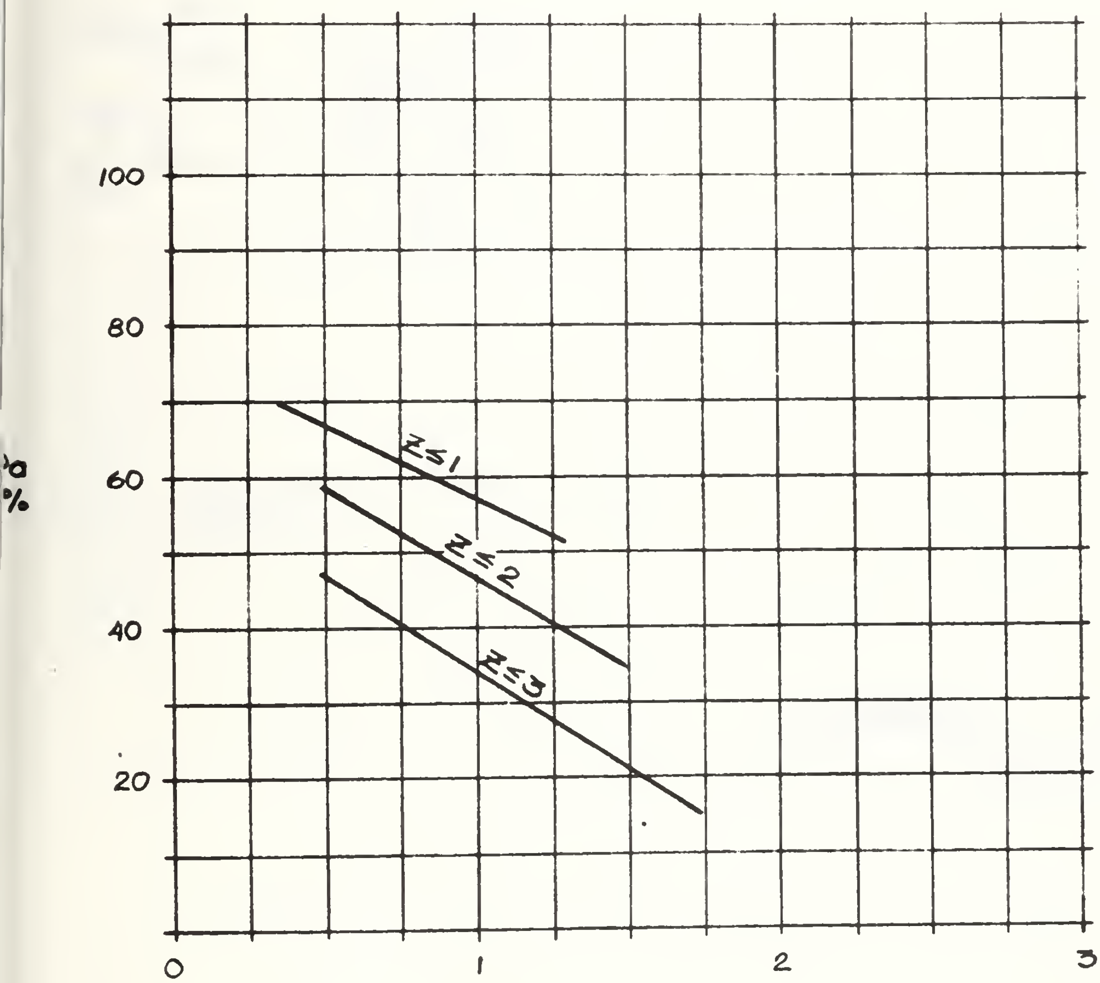
FIG. 1 THE PROBABILITY OF FINDING A VICTIM ALIVE AS A FUNCTION OF TIME. THE AVALANCHE OCCURRED AT T = 0.



Z DESIGNATES THE BURIAL DEPTH OF THE VICTIM IN METERS.

FIG. 2 THE PROBABILITY OF FINDING A VICTIM ALIVE AS A FUNCTION OF TIME USING LINEAR APPROXIMATIONS TO THE DATA OF FIG. 1.



Z DESIGNATES THE BURIAL DEPTH OF THE VICTIM IN METERS.

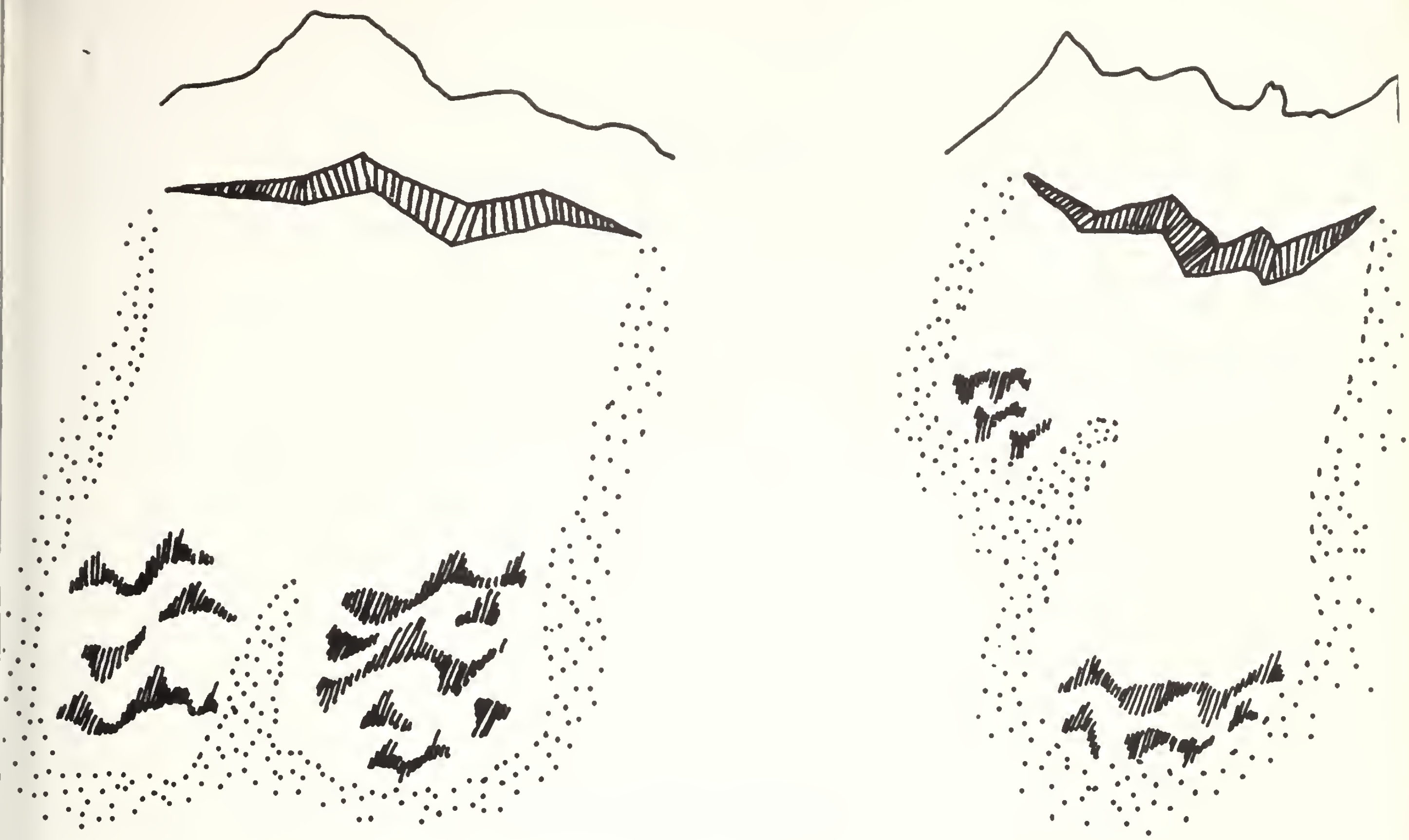


FIG. 3 WHERE IS THE VICTIM BURIED?